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Measurements of Horizontal Flow in the Vicinity of a Building: A Field Study from June to December 1999

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Frank Gouveia and Joe Shinn

Abstract

The pattern of flow around a discrete, yet architecturally complex building is measured through the use of arrays of 2-D sonic anemometers. When the measurements are grouped according to upwind wind direction and normalized by the upwind wind speed, the resulting average vectors reveal persistent patterns of divergence, separation zones, and lee eddies. Additional measurements were made investigating specific details of flow. A pair of 10-m towers supported four levels of anemometers to explore vertical profiles of wind immediately upwind of the building, in an exterior alcove of the building, and in the lee of a line of tall trees. The measurements described in this report may be compared with physical and computational models of flow.

Introduction

The goal of this experiment was to provide measurements of airflow around the exterior of an office building. The resulting data set has been compared to computational models (Calhoun et al., 2000; Calhoun et al., 2004; Emery et al., 2000).

We reviewed the computations from an overly simplified form of CFD model to determine the optimal locations for the wind sensors. Anemometers were located where they would describe significant features of the flow. To reduce the number of sensors required, the wind speed was normalized to wind speed observed at an upwind reference station. This normalization allowed us to combine measurements taken at different times and locations into a complete picture of the horizontal flow. By using eight 2-D sonic anemometers in several "stations", the normalization provided the equivalent of 52 sonic anemometers operating simultaneously.

The long-term weather records from a nearby weather station showed that at the 10-m height the median wind speed is 2.6 m/s. The 95th-percentile is 6 m/s in annually compiled data. During the summer months, the prevalent wind is from the southwest (SW) more than 60% of the time. The frequency of SW winds reduces to about 20% by November.

Measurements

Site

The aerodynamic surfaces of the building are geometrically complicated (Figure 1). This 2-story building includes an inner courtyard, angular and rounded features, sloping roofs, parapets, exterior alcoves and niches, and fenced enclosures. Near this building are dozens of ornamental trees, and a long line of tall, wind-breaking trees. The coordinates of the outline of the building and nearby features are presented in Appendix A. The building and tree coordinates are displayed as a map in Figure 2.

The fetch for the building in the direction of primary interest is relatively unobstructed. The terrain is flat and covered in annual grasses about 0.5 m high. The closest buildings upwind are 150 m due west. The closest buildings SW are over 500 m upwind.

Sensors

Eight sonic anemometers (purchased as Handar model 425, currently marketed as Vaisala model WS 425) were deployed in arrays designed to explore specific areas around the building. The coordinates of these sensors are also presented in Appendix A and shown in Figure 2.

The sonic anemometers measured the two horizontal components of wind. They were selected over the traditional cup and vane anemometers primarily for their nonexistent threshold speed and relatively small sampling

Figure 1. Architect's drawing of the building. The viewpoint is due west of the building looking east.

area. A previous study shows that sonic anemometers perform identically to the cup and vane when the wind is greater than 2 m/s (Gouveia and Lockhart, 1998). In very light winds of less than 0.5 m/s, sonic anemometers are superior to cup and vane because they respond faster and more accurately. For the above stated reasons, sonic anemometers are ideal for studies around buildings where the wind can be light and varies greatly in time and space. The cost of a sonic anemometer is now very close to that of a cup and vane which makes it cost effective to field several anemometers.

Quality control was accomplished by a procedure of inspection of sonic anemometer performance in a slow-speed wind tunnel (1-2.5 m/s). Additionally, we placed all the sonic anemometers at the same height and approximate location near the upwind energy-budget (EB) station for over 3 days (400 to 700 ten-minute periods). These quality control procedures proved the speed measurements were accurate within 3%. The absolute accuracy was approximately equal to the output resolution of 0.1 m/s. The only problems encountered were with one anemometer that had a small, but non-zero calibration offset, two anemometers that required output span adjustments, and one failure due to corrosion within the sonic anemometer case. Since a spare sonic anemometer was quickly brought into service, there was only a trivial amount of data lost.

Data collection

The sonic anemometers measured horizontal wind speed and direction only. They were programmed to provide pulse (speed) and resistance (direction) output to the data acquisition systems (Campbell Scientific, model CR10X). These dataloggers acquired the data in 1-second polls and processed the data into 10-minute averages.

Detail on individual stations

Table 1 summarizes the test series of 13 stations listed in chronological order. The stations are shown in Figure 1, which plots the 54 sonic locations with lines joining positions of the same station.

Stations 1 and 9 were quality control tests. The anemometers were placed near the EB station for a short time. The flow data from this test was not included in this study.

The results from the preliminary CFD-model run indicated that it would be important to resolve the detail near the building. Therefore, the anemometers for stations 2, 3, and 4 were spaced closer together near the building.

Stations 5, 6, and 7 were in the lee. Station 8 was designed to explore the leeward edge effect and possible eddy shedding.

The anemometers were placed in the courtyard of the building for station 10.

Stations 11, 12 and 15 featured two towers with four anemometers each. These three stations explored the vertical structure of wind in an alcove in the lee of the building, immediately upwind of the building, and in the lee of the row of trees. The lowest level of the towers in stations 11 and 12 were used in the horizontal flow pattern discussed in the next section.

Average normalized vectors

The 10-minute averages were combined with data from the upwind EB station. During the course of this study, our goal was to obtain sufficient data when the ambient wind was from the southwest. The average component wind speeds, normalized by the upwind wind speed, were computed for every degree of upwind wind direction as long as the upwind speed was greater than 2 m/s. This criterion for wind speed assured that the flow pattern was being forced by sufficiently strong and relatively coherent upwind conditions, removed most cases of non-neutral stability, and still provided enough data points to provide significant averaging statistics.

Late in the field study, the frequency of strong winds from the SW was significantly reduced, following the historical record. For the months of November and December the upwind speed restriction was lowered to 1 m/s to include more data points into the average statistics. Despite this change in criteria, the stability often remained near neutral due to the decrease in sun angle.

The normalized component data were graphed according to upwind wind direction (UWD) and inspected. See Figure 3 for an example of this graph. The data are expressed using the standard meteorological notation: the *u* component is positive to east, the *v* component is positive to north. Average components were computed for each 1° increment of UWD (Figure 4). These average wind speed components undergo smooth transition in continuous curves along the independent variable of UWD. This analysis showed that the collective of 10-min periods at a given UWD was representative of the flow and repeatable.

The 1° average components were further averaged over 15° angles of UWD centered on cardinal directions. This assured us that the average was not biased by an uneven frequency of reports across a 15° sector. These average speed components comprise the data set for 71 anemometer locations. Appendix B is a complete listing of these data.

Results

Vector patterns

Figures 5 through 10 are compilations of the normalized vectors for narrow bands of UWD centered on these directions: 210, 225, 240, 255, 270, and 285°. The vector without a circle represents the UWD as measured at the EB station. The location of the upwind vector is not accurate in these figures. The length of any

Table 1. Summary of the 13 stations

Station	Description
1	Collocation of all the anemometers for a quality control test.
2	Line extending roughly SSE from the S corner of the building.
3	Line extending roughly from the center of the SE wall.
4	Line extending roughly SSW from the E corner.
5	Line of 4 anemometers NE of the building.
6	Short line of 3 anemometers near N corner.
7	Short line of 3 anemometers near N corner.
8	Two lines of anemometers NNE of the W corner.
9	Collocation of all the anemometers for a quality control test.
10	Line of anemometers inside the courtyard.
11	Anemometers on two towers inside the NW alcove.
12	Two towers 4- and 8-m away from the W wall.
15	Two towers in the lee of the line of trees E.

vector can be compared to this upwind wind vector for relative wind speed. Only the 2.5-m levels were used for these diagrams, a total of 52 locations. The data from stations 1, 9 and 15 were excluded, as well as data from the anemometers from stations 11 and 12 that were not 2.5 m above the ground.

Several flow features are readily apparent when reviewing this set of diagrams. The lee eddy (stations 5, 6, 7 and 8) forms a line of horizontal convergence. Most of the vectors in the courtyard (station 10) are about 180° from the UWD. The vectors from the fourth location away from the center of the southeast wall (station 3) are slightly smaller than its closest neighbors. This is caused by its proximity to an ornamental tree.

Subtle curvature of the wind upstream of the building can be detected, especially in stations 2 and 3. A lee eddy can be seen near the southwest corner of the building. The size of the eddy is small for UWD of 240°, and increases as the wind rotates to 285°.

Vertical profiles

Special experiments were conducted to measure vertical profiles of wind. We selected three diverse locations to conduct these experiments: in a niche near the northwest corner of the building, upwind of the building, and southeast of the building in the lee of the line of trees. Two tilt-up towers were used for these experiments. Sonic anemometers were placed at 2.5, 4.5, 7.2, and 9.0 m above the ground on these portable towers.

Vertical profiles in niche

The wind data collected in an alcove (station 11) show evidence of complicated flow in that architectural feature. Figures 11a and 11b plot the normalized *u* and *v* components for the inner and outer towers, respectively. In these two figures lines connect points from the same UWD. Vertical profiles from the six UWD featured varying amounts of direction shear with height. There is evidence of the rotation of direction with increasing height on both towers: clockwise for 210 and 225°, counterclockwise for 240 through 285°. The flow coming into the alcove, as measured at the outer tower, comes exclusively from the lower levels for all UWDs. When comparing vectors from the two towers, a horizontal, clockwise circulation in the alcove can be found, especially for UWD greater than 240°. See also Figures 8 through 10 for the strong clockwise circulation when the niche is on the windward side of the building.

Vertical profiles upwind of the building

The 9-m towers were placed west of the building (station 12). The positions of the towers were carefully selected to be close to the building, but as far as possible from the various ornamental trees and shrubs, the shallow drainage swale to the west, and the architectural features that detract from the monolithic west wall.

Figures 12a and 12b show the average normalized speed at the two 9-m towers. Again, these normalized speeds are relative to the 2.5-m speed measured at the EB station. Each figure plots five profiles, each representing averages from five UWDs.

It can be seen when comparing these plots that there is a distinct slow-down of the horizontal wind as it approaches the aerodynamic obstruction of the two-story building. Using this information, we can estimate the vertical wind necessary to conserve mass. We need to determine the average horizontal flow from the surface to 10 m at three locations: at the upwind station, 8-m, and 4-m from the building.

Using the average upwind speed (U_{EB}) we constructed upwind profiles of wind speed,

$$U(Z) = U_{EB} \frac{\ln z - \ln z_0}{\ln z_{EB} - \ln z_0}. \qquad (1)$$

Surface roughness (z_0) was computed in this same field (Gouveia & Chapman, 1989) and was found to be about 0.16 m with a displacement of about 0.08 m.

Wind from 240° is perpendicular to west wall of the building. The slow-down of horizontal speed as the flow approaches the building must be compensated with a positive vertical flow via this simple expression,

$$w = \left(\overline{U_{Far}} - \overline{U_{Near}}\right)\frac{\Delta z}{\Delta x}. \qquad (2)$$

The subscripts Near and Far relate to the relative distance from the building. Equation 2 can be used to estimate the average vertical wind in the

Table 2. Vertical speed (*w*, m/s) calculated between the EB-, 8-, 4-m towers, and the wall.

UWD	*w*(EB-8)	*w*(8-4)	*w*(4-wall)
225	0.19	0.91	2.98
240	0.19	0.68	2.88
255	0.19	0.46	2.62
270	0.19	0.34	2.57
285	0.18	0.28	2.62

space between the EB tower, the 8-m tower, the 4-m tower, and west wall of the building (U_{Near} = 0). Table 2 presents the results of Equation 2 for five UWD. The vertical velocity increases as the flow approaches the building. Most of the vertical flow occurs in the last 4 m.

The apparent decrease in vertical wind with increasing UWD (clockwise rotation) reflects the importance of the normal divergence and the aerodynamic qualities of an obstruction. At upwind distances beyond 8 m (the building is about 10 m in height) one would expect little vertical motion on average.

Vertical profiles in lee of trees

The same portable towers were placed 4- and 8-m east of the line of trees (dashed rectangles in Figure 2) and designated as station 15. Unfortunately, the 9-m sensor on the 4-m tower did not return valid data. The profiles of average wind speed in the lee of these trees (Figure 13a and 13b) show a decrease with height. The distribution of foliage of these eucalyptus trees causes this reversal of slope. The densest foliage is elevated. The average height of the trees is 14 meters.

The plot of the normalized components averaged for every degree of UWD features rather sinusoidal curves. The lowest anemometer on the 8-m tower (Figure 14a) is the one least affected by the trees. In fact, some angles of UWD feature a speed-up of the wind at this low level. When the wind is approximately normal to the line of trees, from the east or from the west, the speed at this is on average 20 to 40% higher than the EB station.

By contrast, the anemometer closest to the foliage, the 7-m level of the 4-m tower, exhibits dramatically reduced speeds when in the lee of the trees (Figure 14b).

Conclusions

This report describes wind measurements made in the natural flow around a building. These measurements can be used in several ways to benefit computational and physical models. The vector fields reveal features in the upstream and wake flows that should be imitated by an accurate model.

Limited time and resources forced us to select strategic positions for our anemometers. We effectively multiplied the number of anemometers available by repositioning them, and combining wind vectors according to the upwind wind direction. The wind speeds were normalized to the upwind wind speed with the understanding that the features of flow are scaled by the ambient speed. Our eight anemometers, and subsequent analysis, produced a series of six distinct vector fields around a building, featuring 52 unique locations at the same 2.5-m level. These vector fields have been shown to be reproducible.

Wind tunnel and computer models have some advantages over field studies. Models predict wind at more locations than is possible in the field. Models are also relatively inexpensive to develop, implement, and modify. However, models lack complete connection to natural conditions. Boundary conditions in models are often given as constant and lack the natural scales of motion.

The method of conditional grouping used in this study can be used in future studies. Additionally, faster data collection equipment and 3-D anemometers now allow us to measure turbulent quantities.

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Figure 2. Map of the experiment area, showing the outline of the building, the locations of the sensors in their station groupings, and the outline of the line of eucalyptus trees.

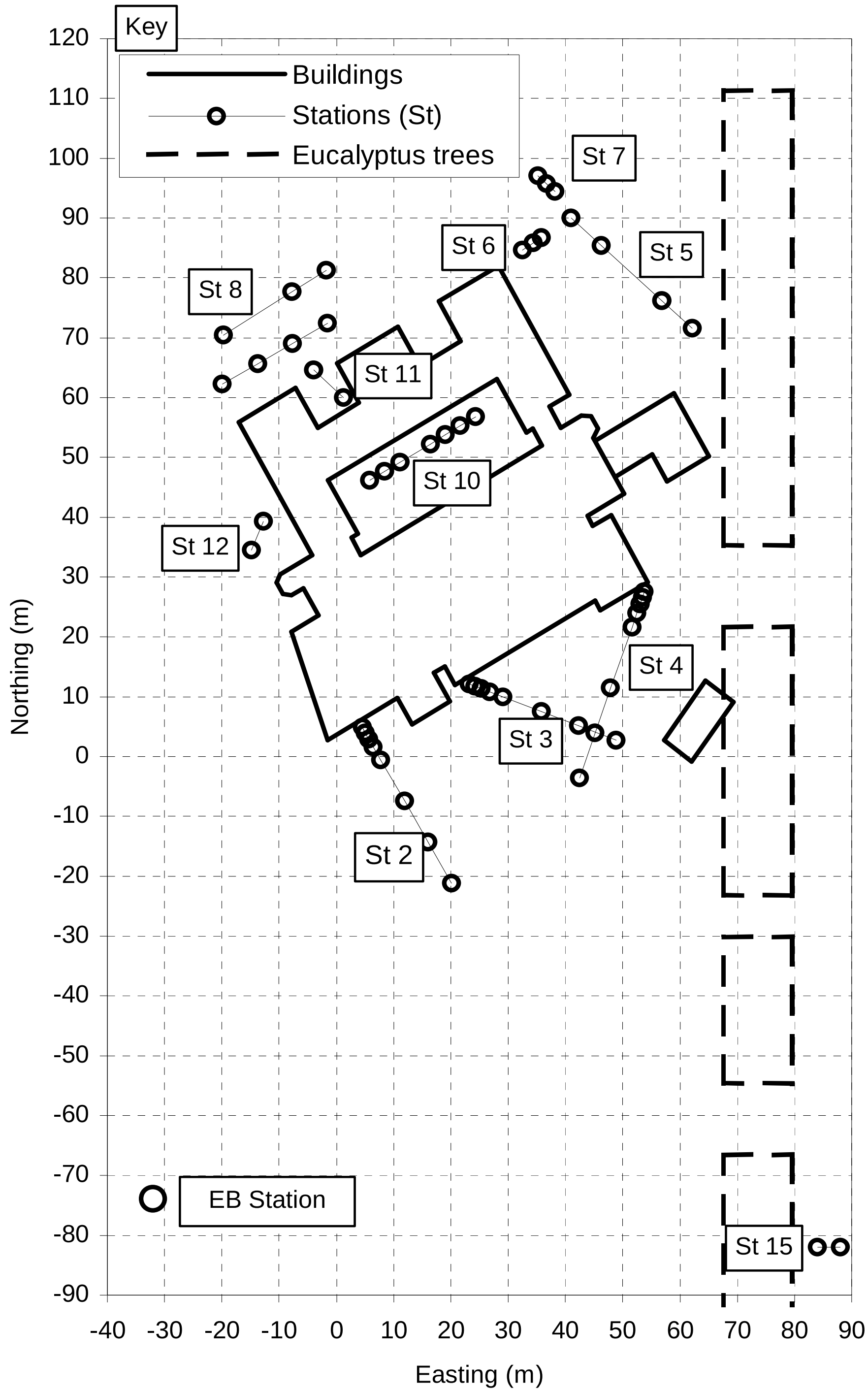


Figure 3. Normalized component speed plotted against the concurrent upwind wind direction. This graph is just one example of the 54 graphs that can be made for each sensor. This graph was made with data from station 8, sensor 8.

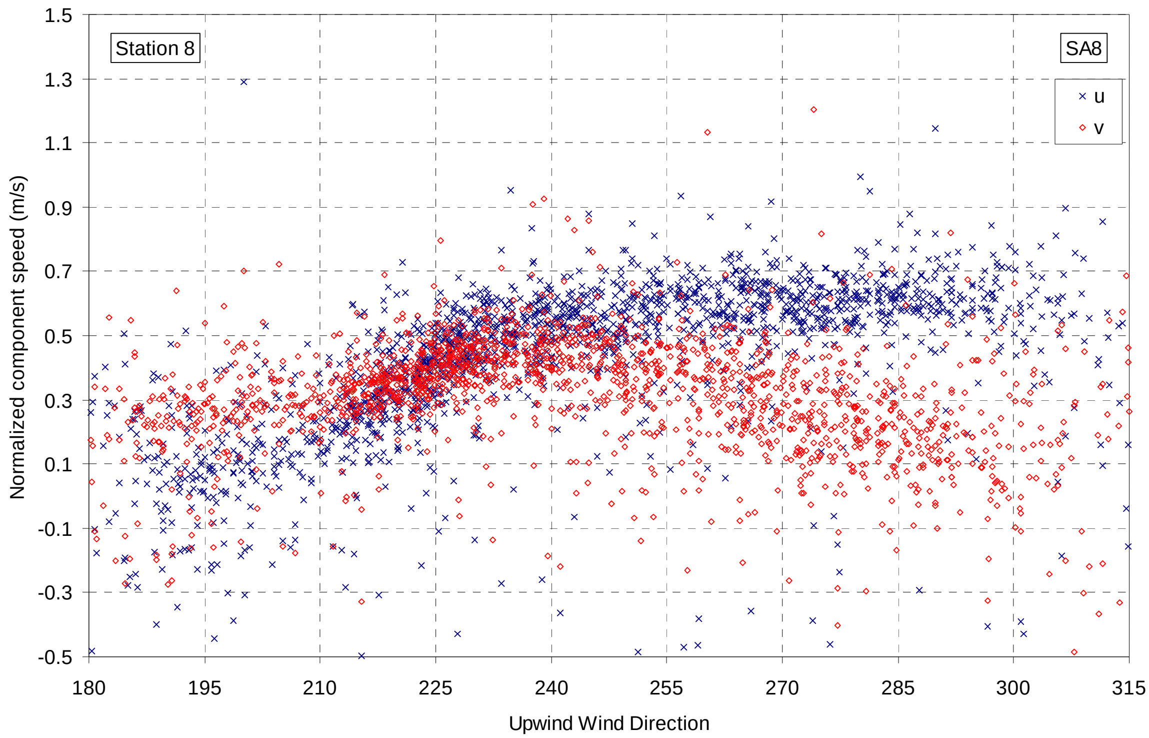


Figure 4. Same as Figure 3, but showing components averaged for each degree of upwind wind direction.

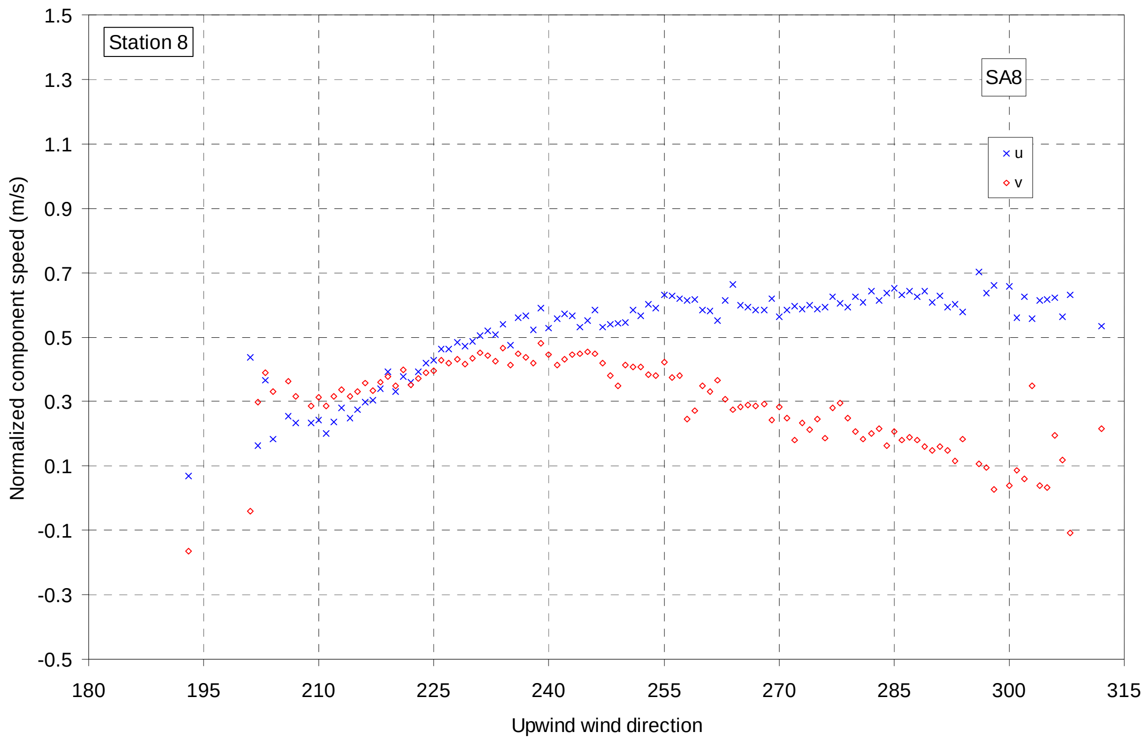


Figure 5. Map of normalized vectors from all 54 sensors when the upwind is from 210°. The sensor locations are at the open circles. The upwind vector, marked without a circle, is near the bottom of the map, although the actual location is off the bottom of the page (see Fig. 2). The length of all vectors is proportional to the average speed at that location divided by the upwind speed. The vectors are pointed away from the location circle toward the average wind direction. The dashed lines are 10 m apart.

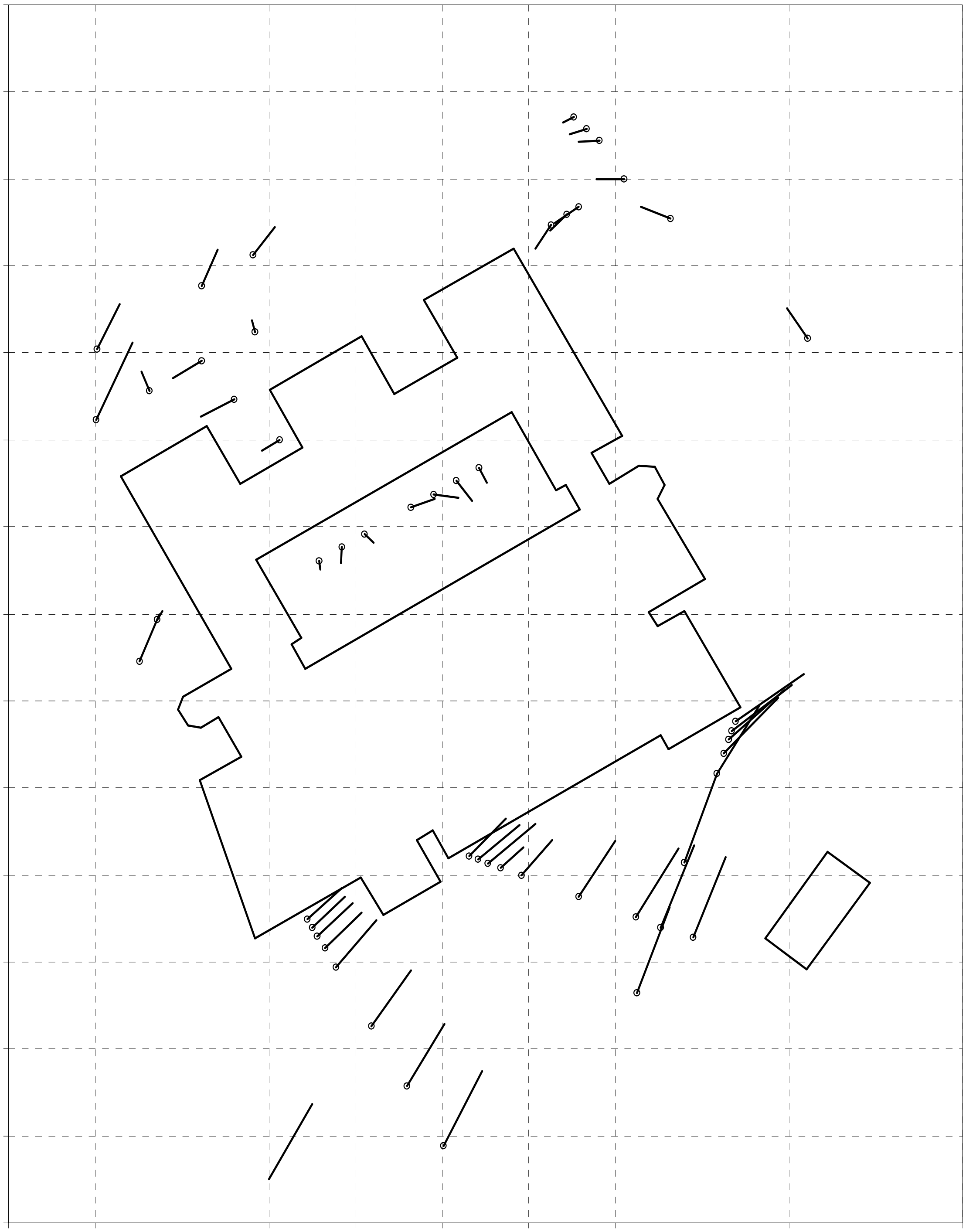


Figure 6. Same as Figure 5 but for upwind direction of 225°.

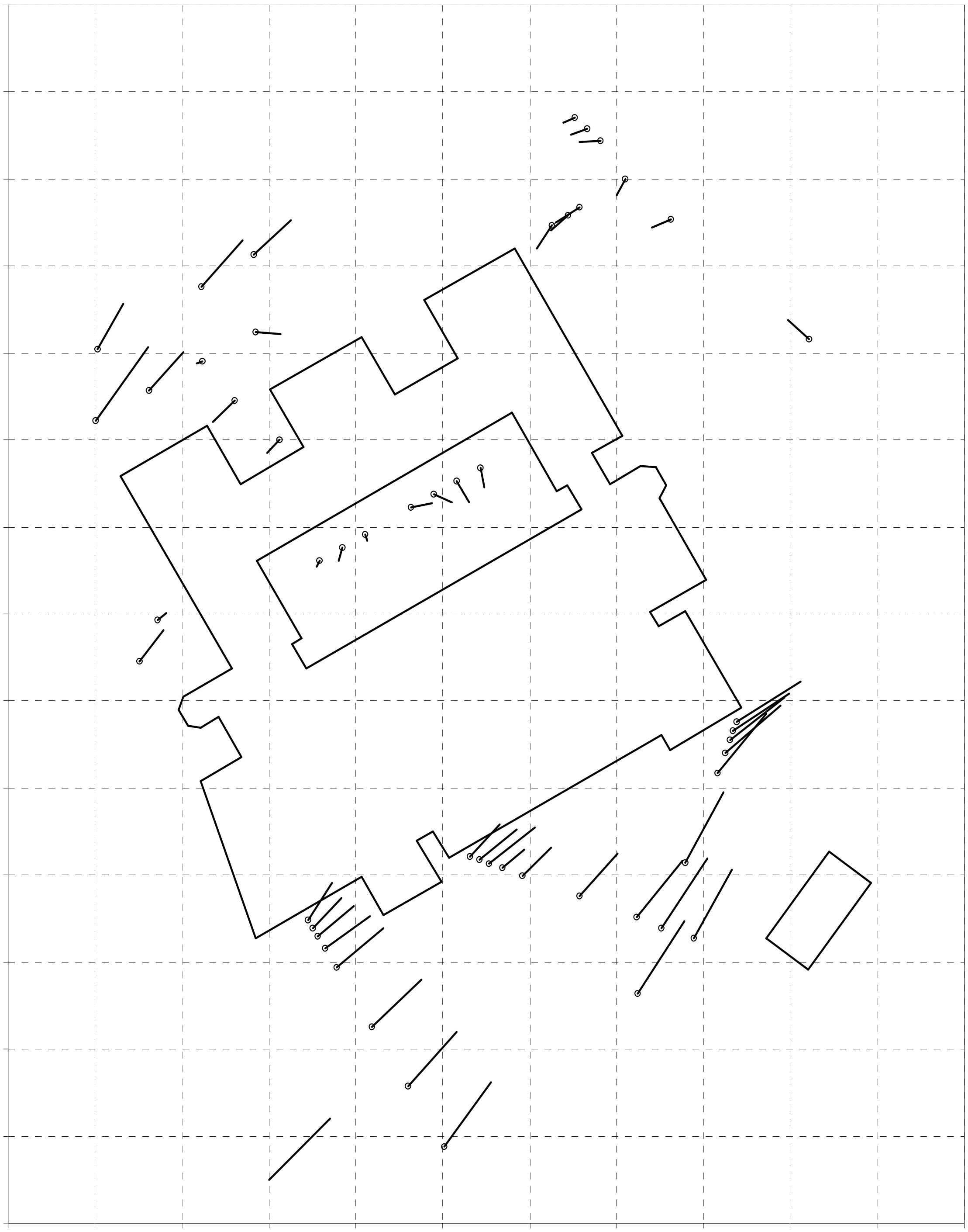


Figure 7. Same as Figure 5 but for upwind direction of 240°.

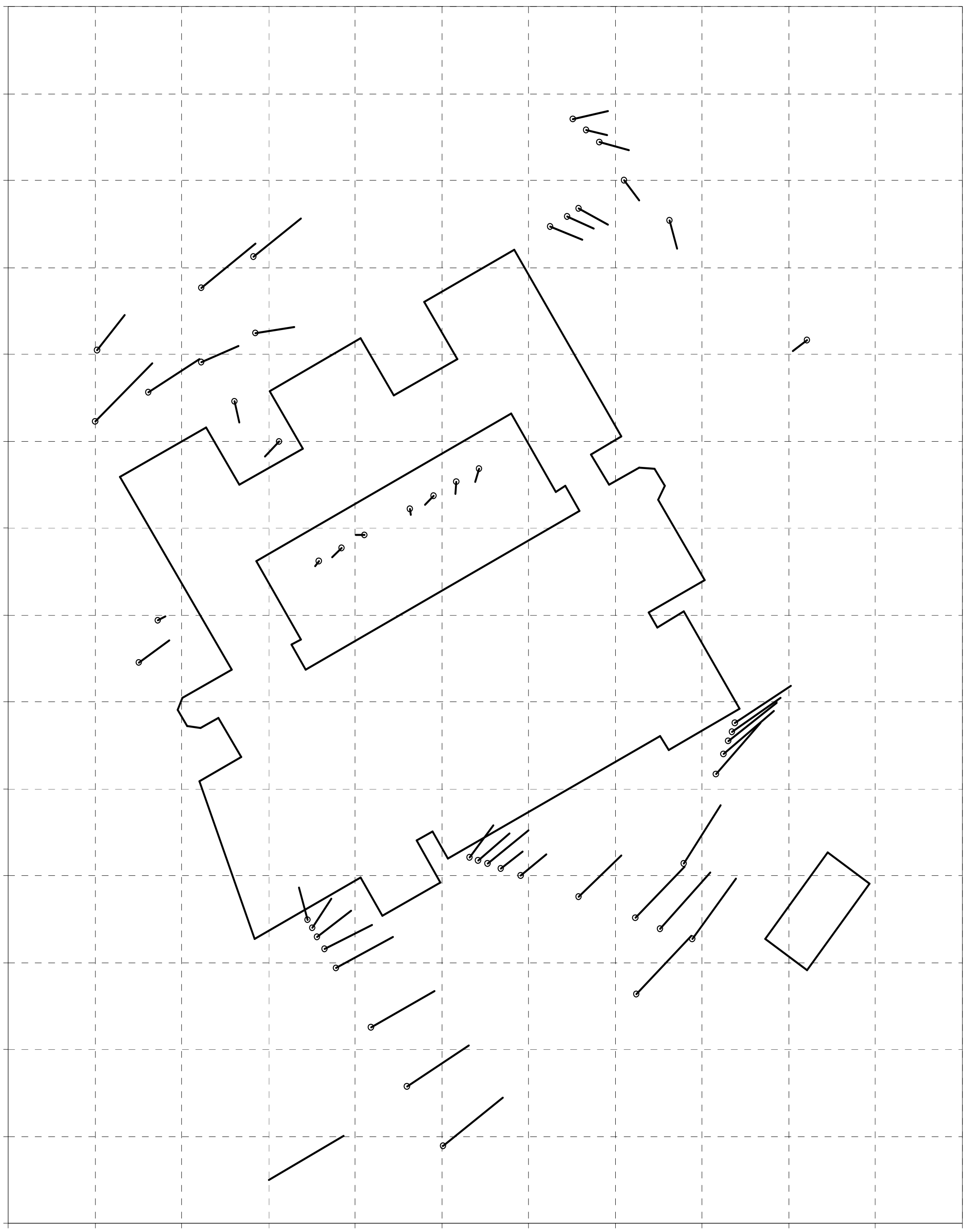


Figure 8. Same as Figure 5 but for upwind direction of 255°.

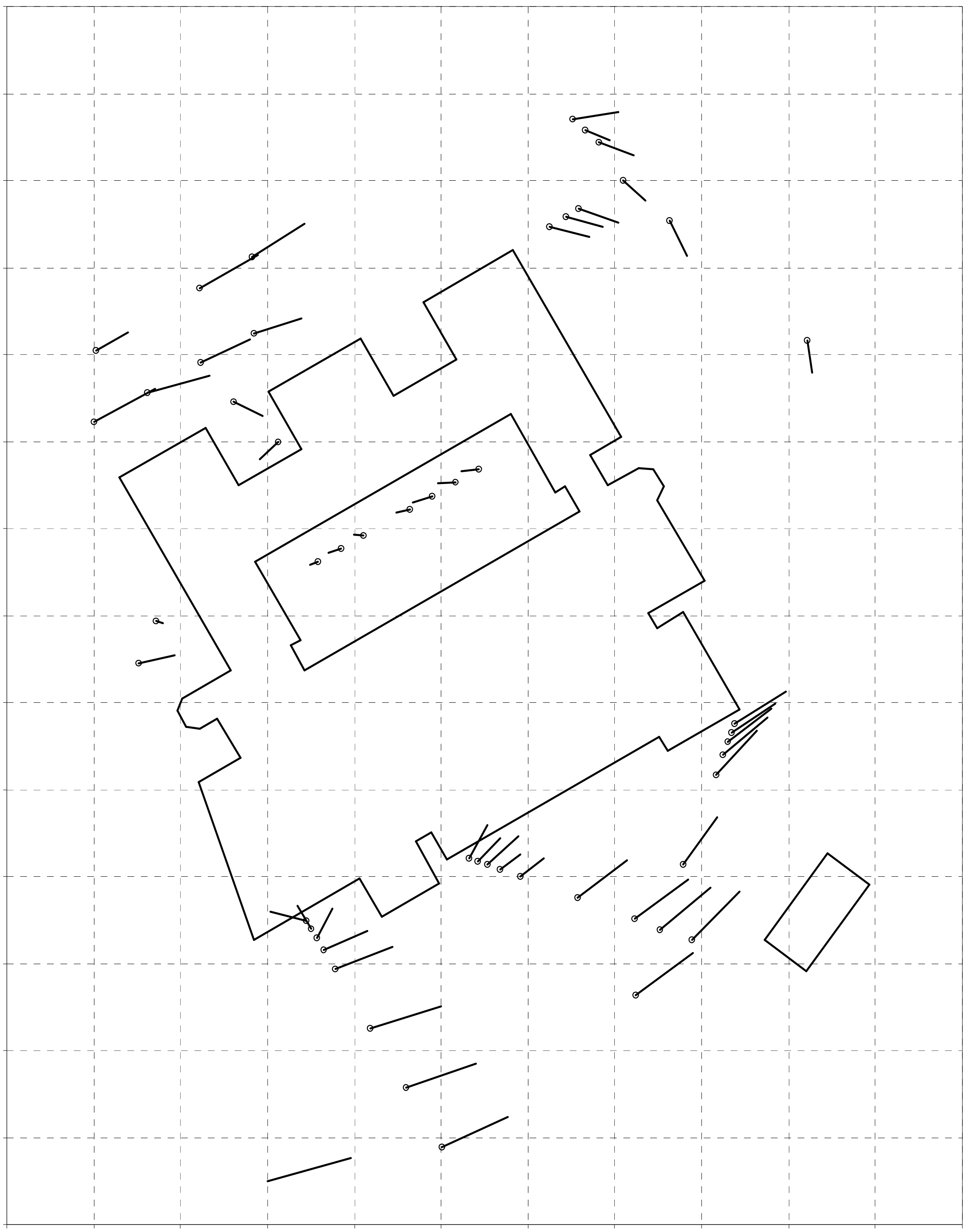


Figure 9. Same as Figure 5 but for upwind direction of 270°.

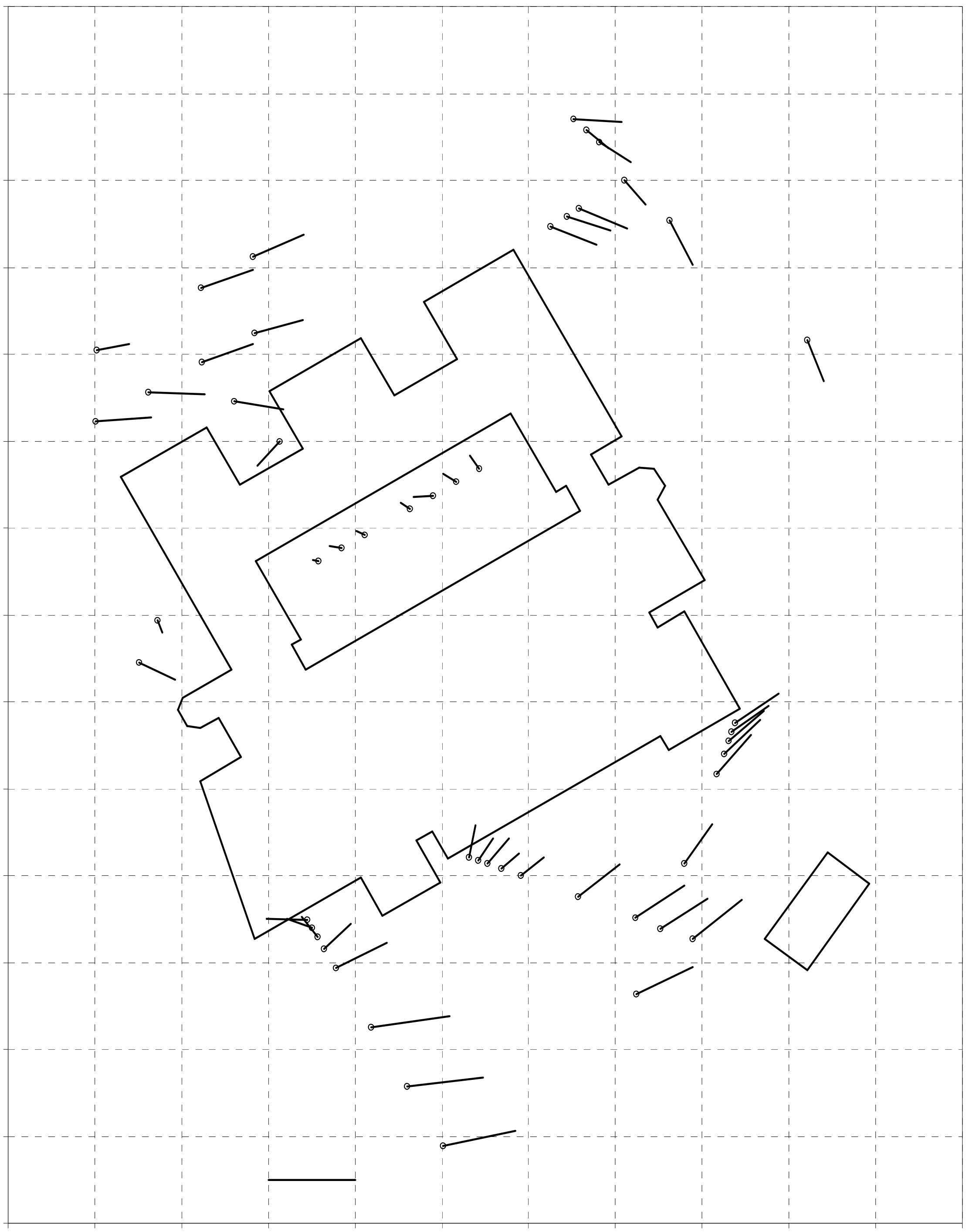


Figure 10. Same as Figure 5 but for upwind direction of 285°.

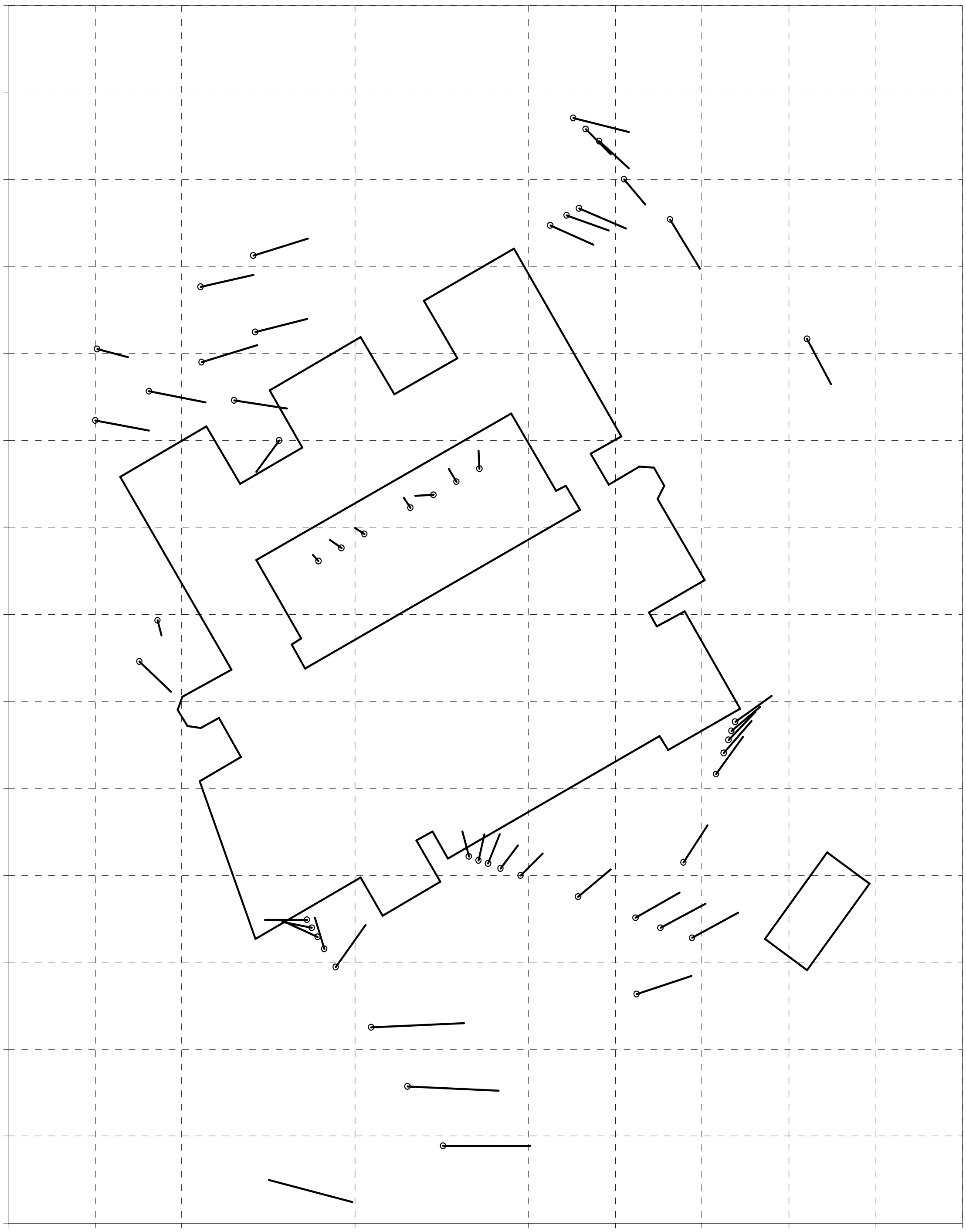


Figure 11a. A display of the normalized vectors from sensors in the niche of the building (station 11). These vectors are from the inner tower in the niche. Each UWD sector and level of tower is represented. The data symbols are the end points of the vectors originating at u=0, v=0. Lines connect data from the same UWD sector. Data from the top of the tower (9.0 m) are on the right side of the diagram, and data from the bottom of the tower (2.5 m) are on the left.

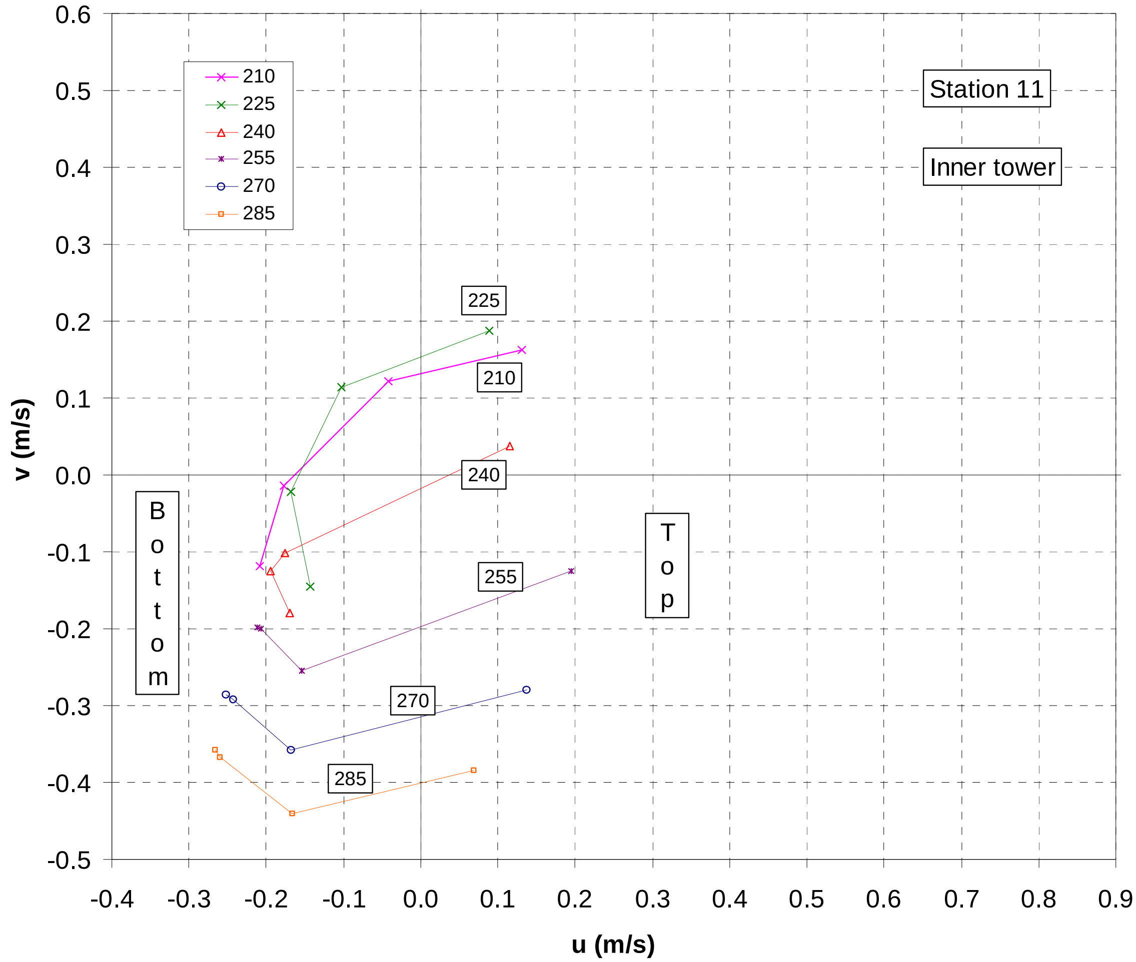


Figure 11b. A display of the normalized vectors from sensors in the niche of the building (station 11). These vectors are from the outer tower in the niche. Each UWD sector and level of tower is represented. The data symbols are the end points of the vectors originating at *u*=0, *v*=0. Lines connect data from the same UWD sector. Data from the top of the tower (9.0 m) are on the upper side of the diagram, and data from the bottom of the tower (2.5 m) are on the lower.

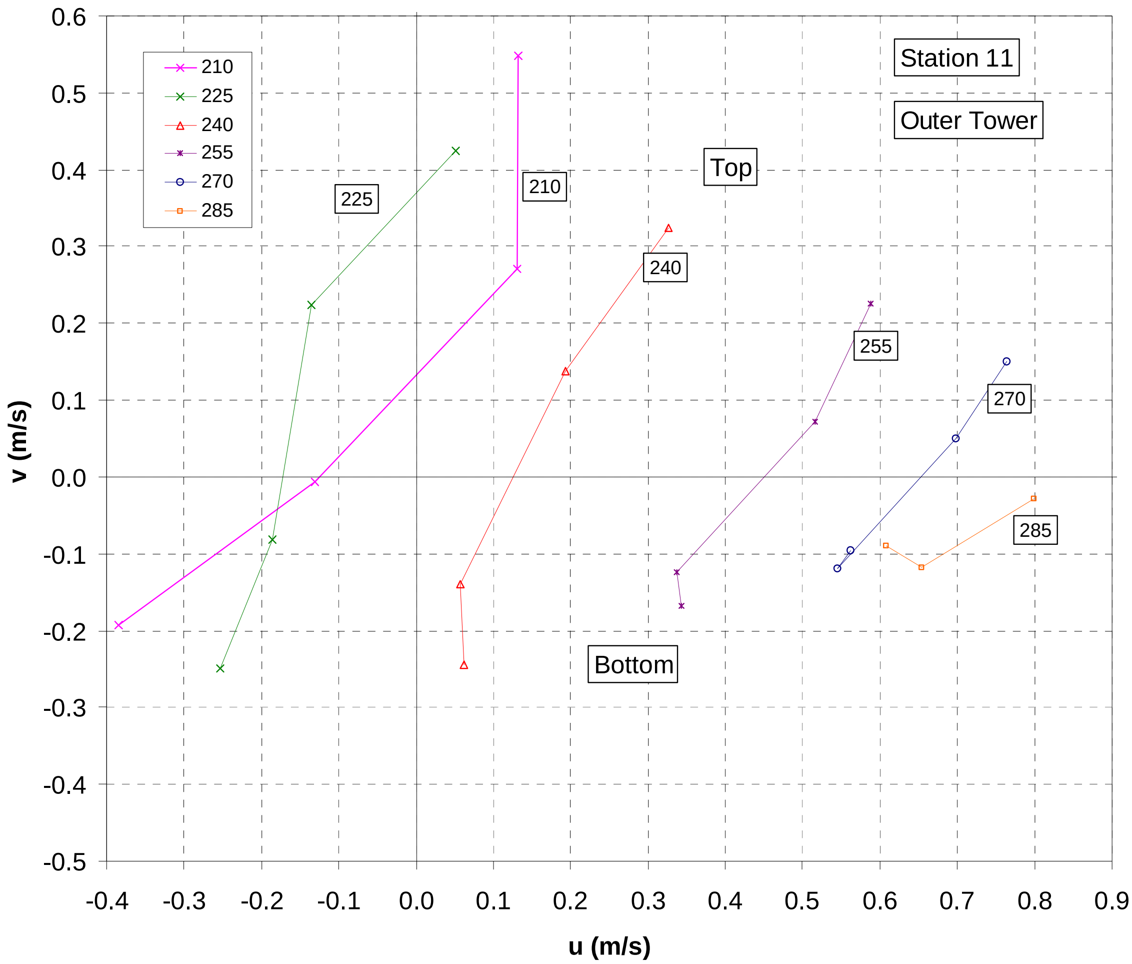


Figure 12a. Profiles of the normalized wind speed from the tower 4-m west of the building (station 12).

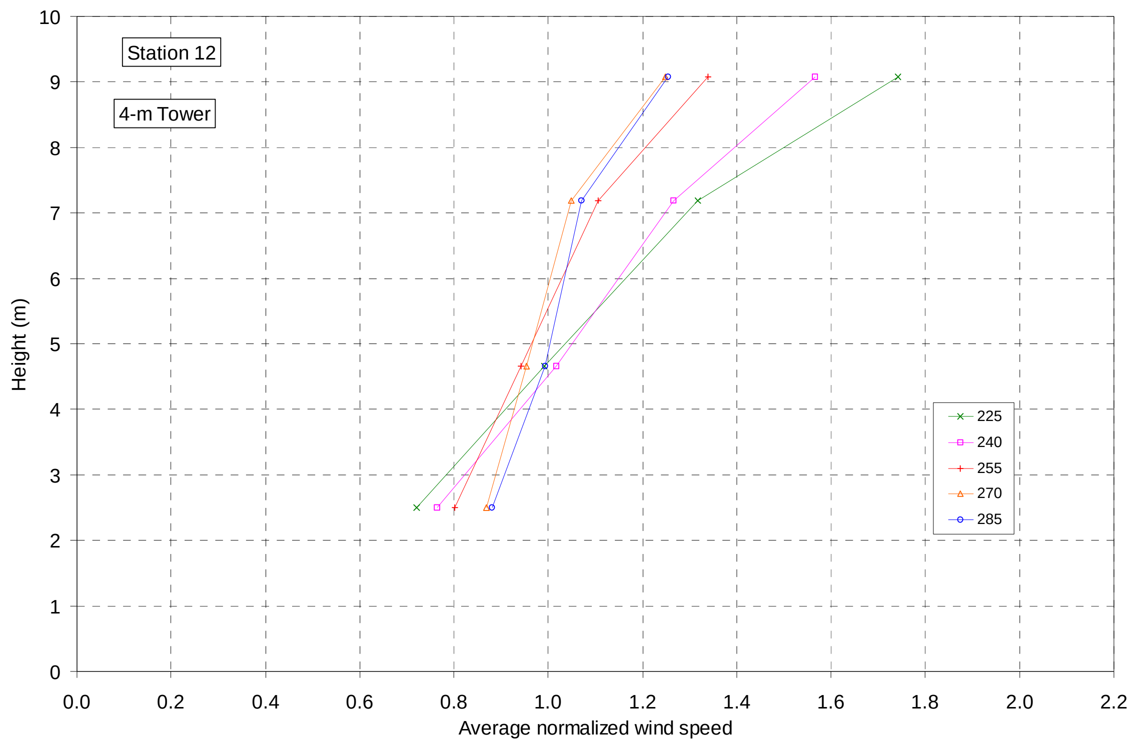


Figure 12b. Profiles of the normalized wind speed from the tower 8-m west of the building (station 12).

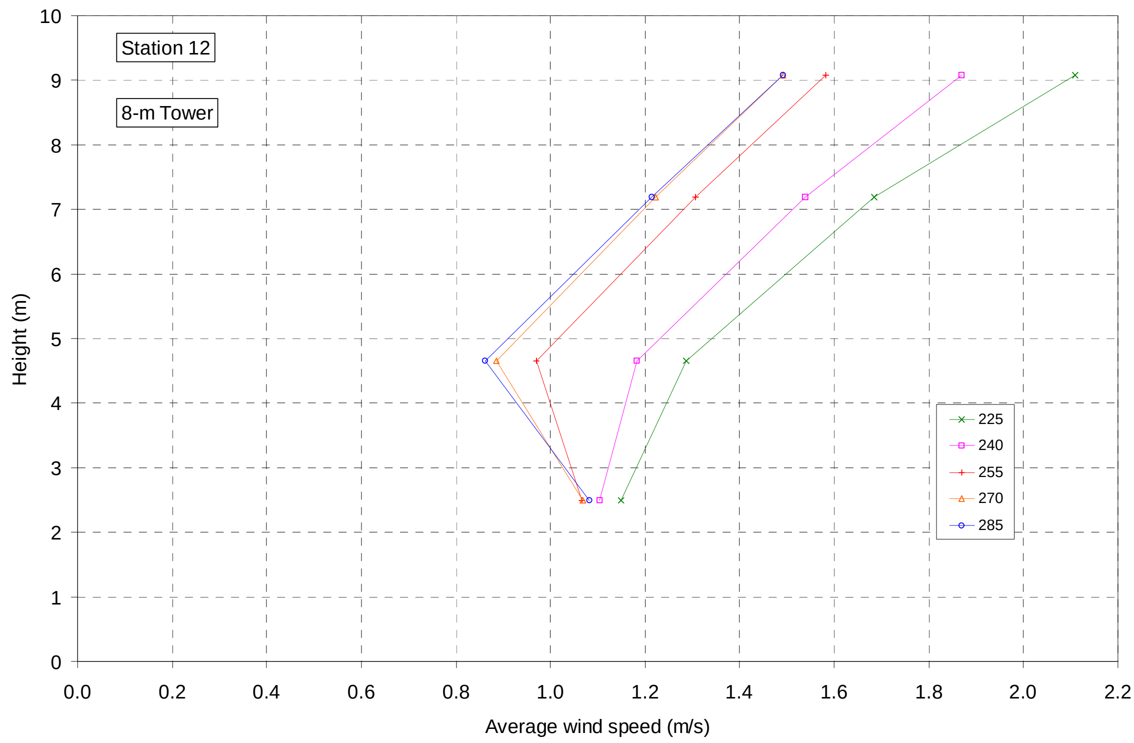


Figure 13a. Profiles of the wind speed from the tower 4-m east of a line of tall trees (station 15).

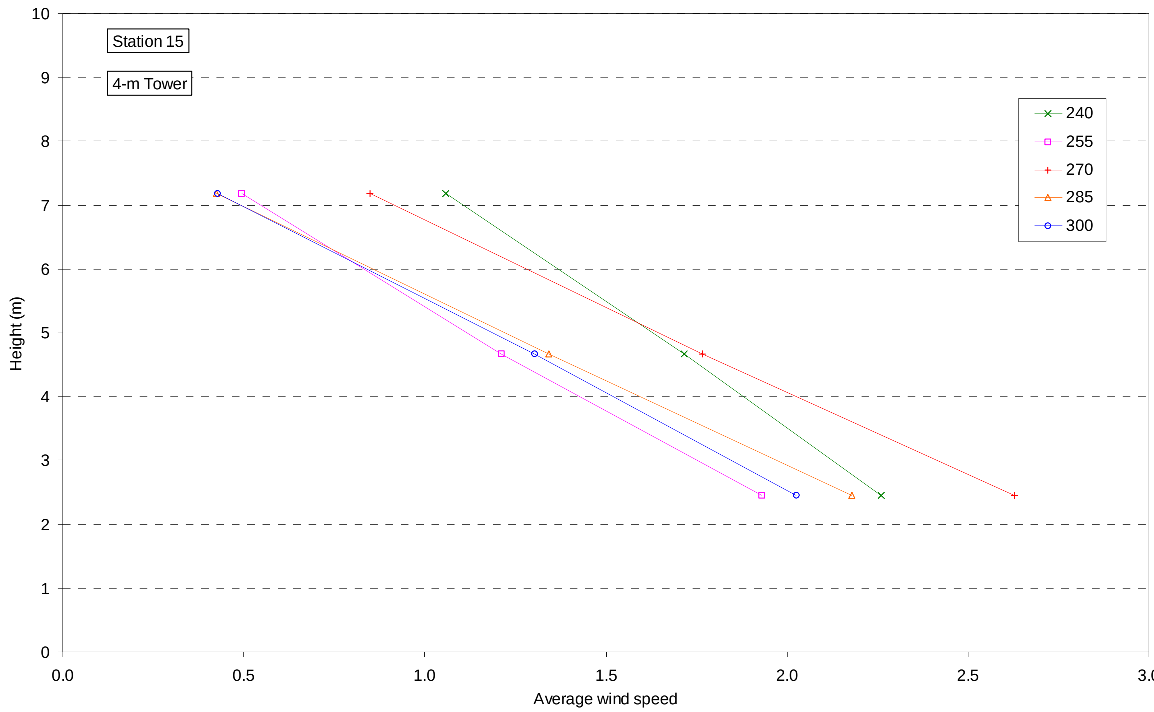


Figure 13b. Profiles of the wind speed from the tower 8-m east of a line of tall trees (station 15).

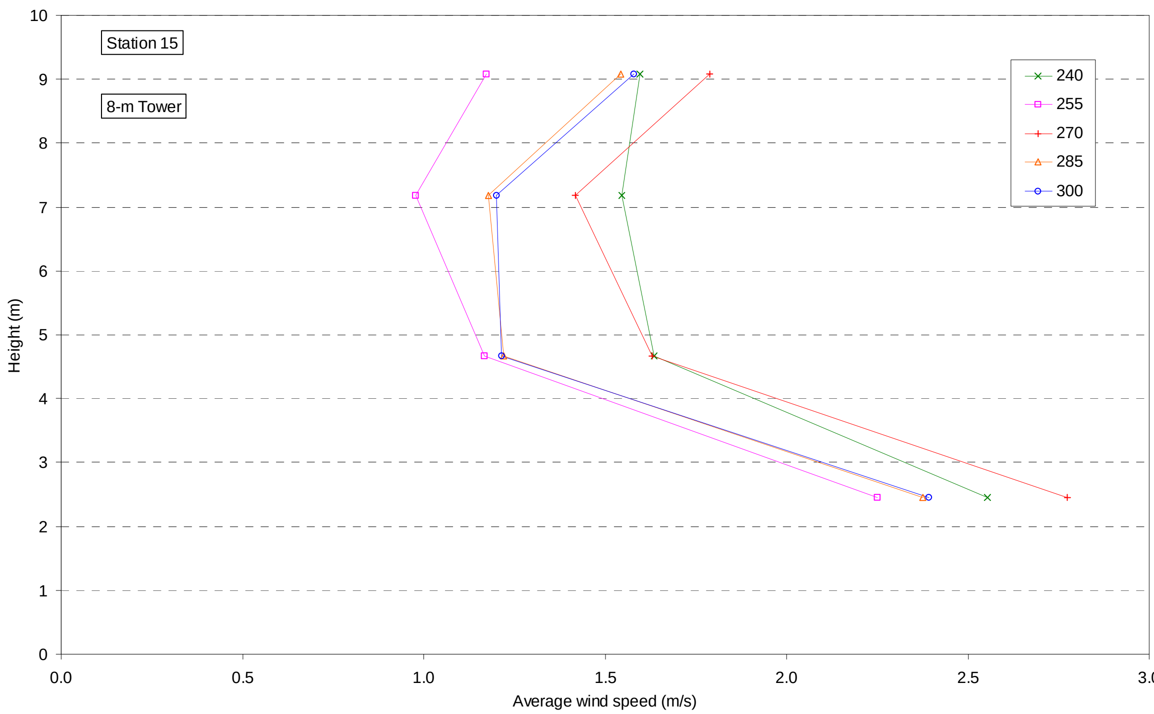


Figure 14a. Normalized wind speed (WS) and component speed (*u* and *v*) from the lowest level of the tower 8-m from the trees (station 15).

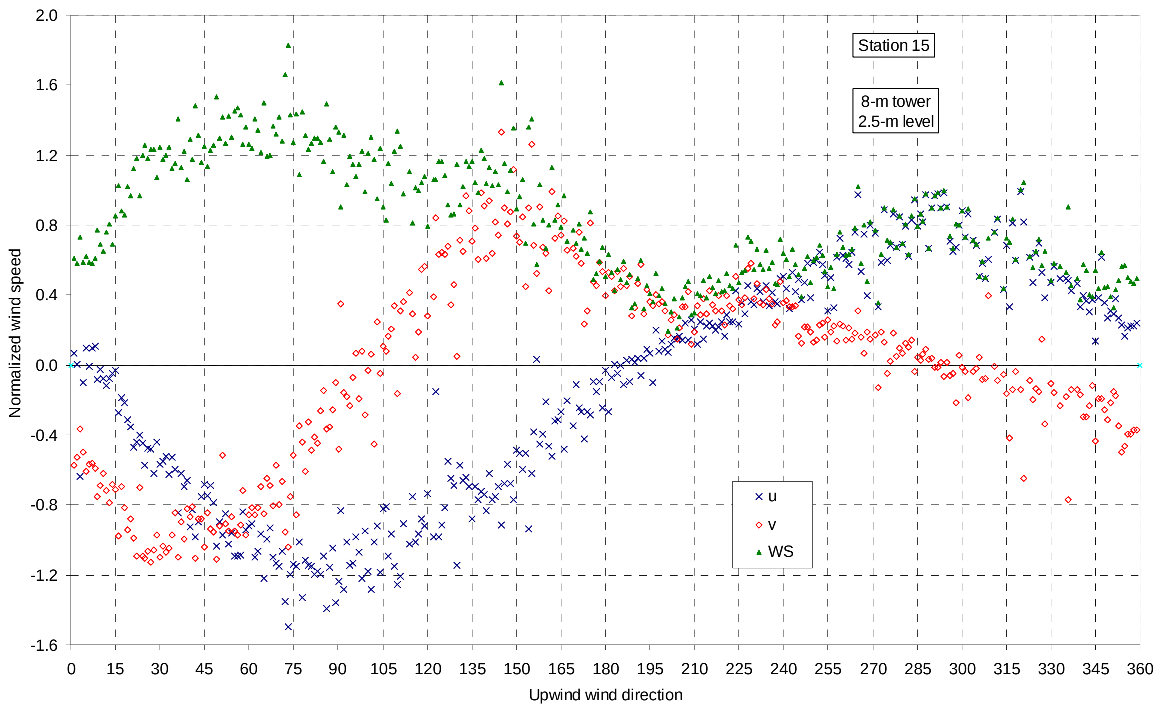
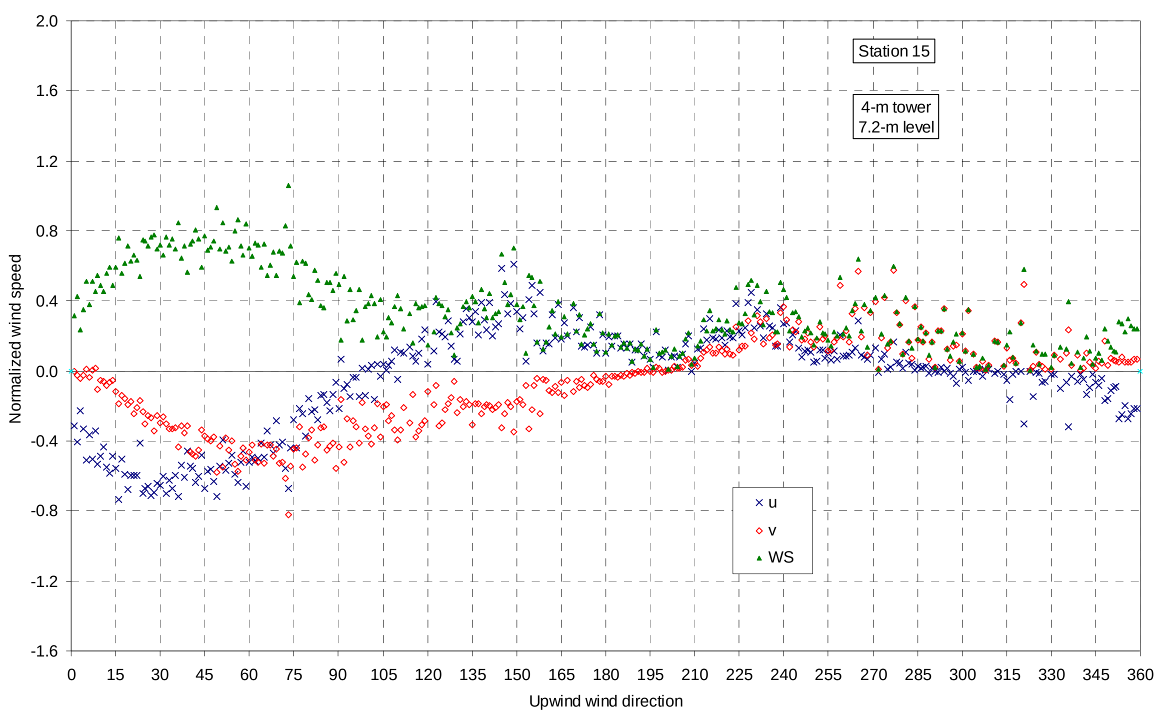


Figure 14b. Normalized wind speed (WS) and component speed (*u* and *v*) from the 7.2-m level of the tower 4-m from the trees (station 15).



APPENDIX A -- Map coordinates for building and vicinity

The following is a list of the coordinates of the outline of the building, the anemometer locations, the line of the eucalyptus trees, and some of the larger trees around the building. The units are in meters relative to a datum point near the SW corner of the building. Every point has an identifier, which is usually a sequence number, and two distances, X and Y. The X values increase toward the East, Y increases towards the North.

Building	X	Y
1	-1.6	2.7
2	10.7	9.8
3	13.2	5.4
4	19.8	9.2
5	17.0	14.0
6	18.9	15.1
7	20.7	12.0
8	45.1	26.1
9	46.1	24.4
10	54.4	29.2
11	47.9	40.4
12	44.8	38.6
13	43.9	40.2
14	50.3	43.9
15	44.9	53.3
16	45.7	54.8
17	44.5	56.9
18	42.7	57.0
19	39.2	54.9
20	37.2	58.5
21	40.7	60.5
22	28.3	82.0
23	17.9	76.1
24	21.8	69.4
25	14.5	65.2
26	10.7	71.9
27	0.1	65.8
28	3.9	59.1
29	-3.3	55.0
30	-7.1	61.6
31	-17.1	55.9
32	-4.3	33.7
33	-9.9	30.5
34	-10.4	29.0
35	-9.3	27.2
36	-7.8	27.0
37	-5.8	28.2
38	-3.1	23.6
39	-7.9	20.8
40	-1.6	2.7

Annex	X	Y
41	57.2	2.7
42	62.1	-0.9
43	69.3	9.1
44	64.5	12.7
45	57.2	2.7
Courtyard		
12	35.9	52.0
13	34.3	54.8
14	33.1	54.2
15	28.0	63.1
16	-1.4	46.2
17	3.8	37.2
18	2.6	36.6
19	4.3	33.7
12	35.9	52.0
Energy Budget Station		
	-32.1	-73.9
Sheet metal fence		
1	45.2	52.8
2	59.0	60.8
3	65.1	50.3
4	57.7	46.0
5	55.1	50.5
6	48.7	46.7
Station 2		
SA1	4.5	4.9
SA2	5.1	3.9
SA3	5.6	3.0
SA4	6.5	1.6
SA5	7.8	-0.6
SA6	11.9	-7.4
SA7	16.0	-14.3
SA8	20.1	-21.2

Station 3	X	Y
SA1	23.2	12.1
SA2	24.2	11.8
SA3	25.3	11.3
SA4	26.8	10.8
SA5	29.1	9.9
SA6	35.7	7.5
SA7	42.3	5.2
SA8	48.9	2.8
Station 4		
SA1	53.8	27.6
SA2	53.4	26.6
SA3	53.0	25.5
SA4	52.5	24.0
SA5	51.6	21.7
SA6	47.9	11.4
SA7	45.2	3.9
SA8	42.4	-3.6
Station 5		
SA4	41.0	90.0
SA5	46.3	85.4
SA7	56.8	76.2
SA8	62.1	71.6
Station 6		
SA1	32.5	84.7
SA2	34.4	85.9
SA3	35.8	86.7
Station 7		
SA1	35.2	97.1
SA2	36.6	95.7
SA3	38.1	94.4
Station 8		
SA1	-19.9	62.2
SA2	-13.8	65.6
SA3	-7.7	69.0
SA4	-1.5	72.4
SA5	-19.8	70.4
SA7	-7.8	77.7
SA8	-1.8	81.3

Station 10	X	Y
SA1	24.3	56.8
SA2	21.6	55.3
SA3	19.0	53.8
SA4	16.4	52.2
SA6	11.1	49.2
SA7	8.5	47.7
SA8	5.8	46.1
Station 11		
SA1	1.3	60.0
SA5	-3.9	64.6
Station 12		
SA1	-12.8	39.4
SA5	-14.9	34.5
Station 15		
SA1	84.0	-82.0
SA5	88.0	-82.0

Eucalyptus trees		
	X	Y
Box 1 NW	67.6	300.0
Box 1 NE	79.6	300.0
Box 1 SE	79.6	139.3
Box 1 SW	67.6	139.3
Box 2 NW	67.6	111.3
Box 2 NE	79.6	111.3
Box 2 SE	79.6	35.3
Box 2 SW	67.6	35.3
Box 3 NW	67.6	21.6
Box 3 NE	79.6	21.6
Box 3 SE	79.6	-23.2
Box 3 SW	67.6	-23.2
Box 4 NW	67.6	-30.2
Box 4 NE	79.6	-30.2
Box 4 SE	79.6	-54.6
Box 4 SW	67.6	-54.6
Box 5 NW	67.6	-66.6
Box 5 NE	79.6	-66.6
Box 5 SE	79.6	-500.0
Box 5 SW	67.6	-500.0

Miscellaneous trees		
	X	Y
A	49.8	68.0
B	43.4	63.1
C	43.5	69.9
D	39.9	75.2
E	34.7	84.0
F	37.1	90.7
G	37.3	97.2
H	42.0	96.6
Willow trees		
A	17.6	86.6
B	13.9	80.8
C	9.4	77.7
D	6.3	83.0
E	-2.5	75.8
Ash trees		
A	10.0	1.7
B	17.8	-5.3
C	28.1	-0.9
D	27.8	8.6
E	34.0	14.0
F	41.2	8.8
G	43.1	17.7

Note: Boxes represent the location of the eucalyptus trees. The boxes are twelve meters wide.

APPENDIX B -- Tables of normalized components of flow

This table of normalized components is arranged according to station and UWD. The values for the unitless normalized *u* and *v* coordinates are under the column headings numbered with the corresponding sonic anemometer. See Appendix A for the locations. For instance, the *u* and *v* coordinates for SA1 and UWD=255° are -0.41 and 0.11, respectively.

Station 2

UWD	u1	u2	u3	u4	u5	u6	u7	u8	v1	v2	v3	v4	v5	v6	v7	v8
213	0.39	0.37	0.40	0.43	0.46	0.46	0.43	0.44	0.36	0.35	0.38	0.41	0.53	0.64	0.71	0.86
225	0.28	0.33	0.41	0.52	0.54	0.56	0.56	0.54	0.42	0.34	0.35	0.37	0.45	0.54	0.63	0.74
240	-0.09	0.21	0.39	0.55	0.65	0.73	0.71	0.69	0.37	0.34	0.30	0.27	0.35	0.42	0.48	0.56
255	-0.41	-0.16	0.19	0.50	0.67	0.81	0.80	0.75	0.11	0.27	0.33	0.22	0.25	0.25	0.28	0.35
270	-0.47	-0.29	-0.18	0.31	0.59	0.91	0.87	0.83	0.02	0.11	0.23	0.28	0.29	0.12	0.11	0.18
285	-0.49	-0.35	-0.33	-0.11	0.35	1.07	1.05	1.01	0.01	0.07	0.15	0.35	0.49	0.04	-0.04	0.01

Station 3

UWD	u1	u2	u3	u4	u5	u6	u7	u8	v1	v2	v3	v4	v5	v6	v7	v8
213	0.42	0.47	0.55	0.26	0.35	0.43	0.49	0.38	0.44	0.39	0.45	0.23	0.40	0.63	0.78	0.93
225	0.34	0.43	0.53	0.25	0.33	0.44	0.53	0.44	0.37	0.35	0.41	0.21	0.32	0.49	0.65	0.78
240	0.28	0.36	0.46	0.25	0.29	0.49	0.57	0.50	0.36	0.32	0.38	0.19	0.25	0.47	0.59	0.69
255	0.21	0.26	0.36	0.24	0.27	0.56	0.61	0.55	0.38	0.27	0.32	0.18	0.21	0.43	0.45	0.55
270	0.07	0.17	0.24	0.21	0.26	0.47	0.56	0.57	0.37	0.26	0.30	0.18	0.21	0.37	0.37	0.45
285	-0.08	0.07	0.13	0.20	0.25	0.37	0.51	0.53	0.29	0.29	0.34	0.26	0.26	0.31	0.29	0.29

Station 4

UWD	u1	u2	u3	u4	u5	u6	u7	u8	v1	v2	v3	v4	v5	v6	v7	v8
210	0.78	0.69	0.64	0.62	0.50	0.38	0.39	0.38	0.55	0.53	0.58	0.63	0.78	1.01	0.95	0.99
225	0.74	0.65	0.63	0.64	0.55	0.43	0.53	0.54	0.46	0.43	0.48	0.55	0.68	0.81	0.80	0.83
240	0.65	0.56	0.55	0.58	0.51	0.42	0.58	0.63	0.42	0.39	0.43	0.50	0.59	0.66	0.64	0.67
255	0.59	0.51	0.49	0.51	0.47	0.38	0.59	0.66	0.37	0.33	0.37	0.42	0.50	0.54	0.48	0.49
270	0.50	0.42	0.41	0.42	0.40	0.32	0.54	0.65	0.33	0.30	0.34	0.38	0.45	0.45	0.34	0.31
285	0.42	0.33	0.31	0.32	0.31	0.28	0.52	0.63	0.31	0.28	0.33	0.38	0.42	0.43	0.28	0.20

Station 5

UWD	u4	u5	u7	u8	v4	v5	v7	v8
210	-0.32	-0.33	-0.24	-0.14	0.00	0.14	0.35	0.46
225	-0.10	-0.22	-0.24	-0.09	-0.19	-0.10	0.21	0.39
240	0.17	0.09	-0.17	-0.07	-0.23	-0.33	-0.12	0.12
255	0.25	0.21	0.06	0.12	-0.23	-0.41	-0.37	-0.27
270	0.24	0.26	0.18	0.23	-0.27	-0.51	-0.47	-0.42
285	0.24	0.34	0.27	0.28	-0.28	-0.57	-0.51	-0.49

Station 6

UWD	u1	u2	u3	v1	v2	v3
210	-0.17	-0.20	-0.28	-0.27	-0.18	-0.17
225	0.15	0.07	0.05	-0.31	-0.24	-0.28
240	0.36	0.31	0.34	-0.14	-0.14	-0.19
255	0.45	0.43	0.46	-0.12	-0.11	-0.16
270	0.53	0.50	0.56	-0.20	-0.17	-0.22
285	0.50	0.49	0.55	-0.22	-0.18	-0.23

Station 7

UWD	u1	u2	u3	v1	v2	v3
210	-0.13	-0.19	-0.24	-0.06	-0.07	-0.02
225	0.37	0.15	0.20	0.09	-0.10	-0.16
240	0.40	0.24	0.35	0.09	-0.05	-0.10
255	0.53	0.27	0.40	0.07	-0.11	-0.15
270	0.56	0.26	0.36	-0.04	-0.20	-0.23
285	0.64	0.29	0.34	-0.16	-0.28	-0.31

Station 8

UWD	u1	u2	u3	u4	u5	u7	u8	v1	v2	v3	v4	v5	v7	v8
210	0.43	-0.08	-0.33	-0.04	0.26	0.19	0.25	0.89	0.22	-0.19	0.13	0.51	0.42	0.31
225	0.60	0.40	-0.07	0.29	0.30	0.47	0.43	0.84	0.44	-0.02	-0.02	0.52	0.53	0.40
240	0.65	0.58	0.42	0.45	0.32	0.62	0.55	0.67	0.37	0.19	0.07	0.41	0.50	0.44
255	0.70	0.70	0.57	0.55	0.37	0.67	0.61	0.38	0.20	0.26	0.17	0.21	0.38	0.38
270	0.64	0.65	0.59	0.56	0.37	0.60	0.59	0.05	-0.03	0.21	0.15	0.07	0.20	0.24
285	0.61	0.65	0.63	0.60	0.36	0.60	0.63	-0.11	-0.13	0.20	0.15	-0.09	0.14	0.19

Station 10

UWD	u1	u2	u3	u4	u6	u7	u8	v1	v2	v3	v4	v6	v7	v8
210	0.09	0.18	0.28	0.28	0.10	-0.01	0.01	-0.18	-0.24	-0.04	0.09	-0.11	-0.19	-0.10
225	0.05	0.14	0.20	0.24	0.02	-0.04	-0.03	-0.22	-0.24	-0.09	0.04	-0.08	-0.15	-0.07
240	-0.05	-0.01	-0.10	0.01	-0.10	-0.10	-0.04	-0.15	-0.13	-0.11	-0.08	0.00	-0.10	-0.05
255	-0.20	-0.20	-0.22	-0.15	-0.11	-0.14	-0.09	-0.02	-0.01	-0.07	-0.04	0.01	-0.04	-0.03
270	-0.11	-0.14	-0.23	-0.11	-0.09	-0.14	-0.06	0.15	0.09	-0.02	0.06	0.04	0.03	0.02
285	0.00	-0.08	-0.21	-0.07	-0.11	-0.13	-0.07	0.20	0.14	-0.01	0.12	0.07	0.09	0.06

Station 11

UWD	u1	u2	u3	u4	u5	u6	u7	u8	v1	v2	v3	v4	v5	v6	v7	v8
210	-0.21	-0.18	-0.04	0.13	-0.38	-0.13	0.13	0.13	-0.12	-0.01	0.12	0.16	-0.19	-0.01	0.27	0.55
225	-0.14	-0.17	-0.10	0.09	-0.25	-0.19	-0.14	0.05	-0.15	-0.02	0.11	0.19	-0.25	-0.08	0.22	0.42
240	-0.17	-0.19	-0.18	0.12	0.06	0.06	0.19	0.33	-0.18	-0.12	-0.10	0.04	-0.24	-0.14	0.14	0.32
255	-0.21	-0.21	-0.15	0.19	0.34	0.34	0.52	0.59	-0.20	-0.20	-0.25	-0.12	-0.17	-0.12	0.07	0.23
270	-0.25	-0.24	-0.17	0.14	0.56	0.55	0.70	0.76	-0.29	-0.29	-0.36	-0.28	-0.10	-0.12	0.05	0.15
285	-0.27	-0.26	-0.17	0.07	0.61	0.65	0.80	0.87	-0.36	-0.37	-0.44	-0.38	-0.09	-0.12	-0.03	0.03

Station 12

UWD	u1	u2	u3	u4	u5	u6	u7	u8	v1	v2	v3	v4	v5	v6	v7	v8
210	0.06	0.18	0.14	0.25	0.22	0.18	0.26	0.38	0.10	0.21	0.47	0.71	0.54	0.50	0.72	0.89
225	0.09	0.36	0.28	0.38	0.27	0.30	0.41	0.54	0.07	0.17	0.45	0.60	0.36	0.42	0.55	0.68
240	0.09	0.37	0.39	0.48	0.34	0.38	0.53	0.65	0.04	0.04	0.33	0.44	0.25	0.30	0.35	0.44
255	0.08	0.35	0.43	0.52	0.42	0.38	0.55	0.67	-0.02	-0.09	0.17	0.25	0.09	0.13	0.12	0.45
270	0.06	0.27	0.45	0.52	0.42	0.38	0.53	0.64	-0.14	-0.33	-0.03	0.08	-0.20	-0.07	-0.10	-0.03
285	0.05	0.21	0.46	0.55	0.37	0.34	0.49	0.63	-0.18	-0.44	-0.17	-0.05	-0.34	-0.19	-0.24	-0.18

Station 15

UWD	u1	u2	u3	u4	u5	u6	u7	u8	v1	v2	v3	v4	v5	v6	v7	v8
210	0.74	0.48	0.06		0.61	0.27	0.22	0.18	0.36	0.24	0.14		0.73	0.30	0.32	0.32
225	0.74	0.53	0.15		0.61	0.38	0.32	0.31	0.30	0.22	0.26		0.61	0.35	0.39	0.40
240	0.82	0.57	0.22		0.73	0.47	0.39	0.42	0.11	0.08	0.21		0.35	0.26	0.30	0.32
255	0.97	0.58	0.18		1.05	0.55	0.44	0.53	-0.09	-0.07	0.09		0.22	0.12	0.16	0.20
270	0.96	0.61	0.26		1.03	0.59	0.49	0.64	-0.31	-0.20	0.08		-0.08	0.02	0.08	0.12
285	1.05	0.64	0.20		1.28	0.65	0.64	0.83	-0.53	-0.32	0.03		-0.22	-0.07	0.02	0.06